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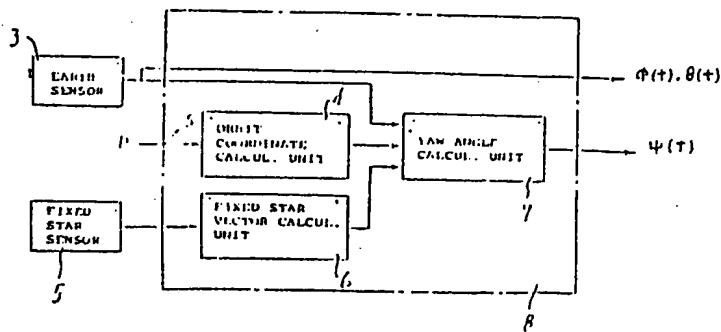
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Attitude angle calculation apparatus for a geostationary satellite.

Attitude angle calculation apparatus is disclosed for calculating an attitude angle of a satellite very precisely. An earth sensor (3) detects the amount of deviation of an angle defined between a predetermined axis of the satellite and a straight line connecting the satellite and the geocentre of the earth. A fixed-star sensor (5) detects a physical intermatrix of

a fixed star. A yaw angle determination device (4,6,7), in response to orbital position information (D) of the satellite sent from a ground station and outputs of the earth sensor and the fixed-star sensor, determines the yaw angle ($\psi(t)$) of the satellite, independently of the roll angle ($\phi(t)$) or the pitch angle ($\theta(t)$) thereof.

FIG. 4



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ATTITUDE ANGLE CALCULATION APPARATUS FOR A
GEOSTATIONARY SATELLITE

This invention relates to an attitude angle calculation apparatus for use in precisely controlling the attitude of a geostationary satellite, more particularly an earth-directed satellite the attitude of which is controlled with respect to the earth in three orthogonal axes.

For an earth surveillance satellite or a communications satellite, in order to maintain a predetermined orientation of an antenna or measuring device with respect to the earth, it is necessary to align a specified axis of the satellite with a straight line connecting the satellite and the earth.

An attitude angle calculation apparatus is used to calculate the angular relationship of a coordinate system of the satellite with respect to a line connecting the satellite and the earth and a line orthogonal to a plane including the orbit of the satellite. An attitude control device controls the attitude angle of the satellite so that the result of the calculation performed by the attitude angle calculation apparatus becomes zero, to thereby maintain a predetermined axis of the satellite directed towards an object.

Referring to Fig. 1 of the accompanying drawings, typically a conventional attitude angle calculation apparatus operates to detect relative deviation angles

- 2 -

ϕ and θ of the Z_B axis of the satellite, which is to be directed to the earth A, from the orbital coordinate system (X_0, Y_0, Z_0) measured by an earth sensor mounted on the satellite. In detail, the roll angle ϕ , which is the angle of rotation of the Z_B axis of the satellite about its X_B axis from the Z_0 axis of the orbital coordinate system, is detected by the earth sensor on the basis of the difference of a scanning width defined by fields of sight B_1 and B_2 of the earth sensor, and the pitch angle θ , which is the angle of rotation of the Z_B axis of the satellite about its Y_B axis, on the basis of the amount of deviation of a reference pulse having a transmitting direction c , measured from the centre of the scanning pulse. However, in such a conventional attitude angle calculation apparatus, it is impossible to measure the yaw angle ψ , which is the angle of rotation of the satellite about its axis Z_B .

In order to overcome this problem, it has been proposed to measure the yaw angle ψ by using a fixed-star sensor mounted on the satellite. Fig. 2 shows the concept

of such a proposal in which the star Polaris 2 (α -Urae Monalis) is detected by the fixed-star sensor directed along the $-Y_B$ axis of the satellite such that a center of the field of sight 1 of the fixed-star sensor is directed to Polaris 2. Assuming coordinates (Z, X) of Polaris 2 in the field of sight 1 of the fixed-star sensor, the yaw angle ψ can be calculated as follows (provided that the satellite is in a stationary orbit) with the roll deviation and the pitch deviation always being zero, and the tilt of the orbit also being zero:

$$\psi = -(X + E_p \sin \alpha), \alpha \in [0, 2\pi], \quad \dots (1)$$

where E_p is the declination of Polaris 2 and α is the difference between the right ascension of Polaris 2 and the right ascension of the satellite. Since, however, it is difficult for a practical satellite to maintain the angles θ and ϕ and the tilting of the orbit at zero, the nonzero angles θ and ϕ and the orbital conditions of the satellite affect the measured value (Z, X) of the fixed star, and it is impossible to separate them from each other. Therefore, it is impossible to measure the yaw angle ψ precisely.

In another approach, a sun sensor is used as the fixed-star sensor. The sun sensor is mounted on the satellite with the field of sight thereof being in

coincide with the $-X_B$ axis of the satellite. In this case, the variation Δn of the angle of incidence n of the sun is detected.

Fig. 3 shows the concept of the latter. In Fig. 3, reference characters I, O, N, L, M, S and L' depict the orbital plane, the center of the earth A, a direction normal to the orbital plane, a cross line of a plane including a vector \vec{S} in the direction of the sun and a line ON and the orbital plane l, a point in the orbital plane l separated from the line L by 90° , an angle between a line OM and a line from the center O to a point P on the orbit, and a line parallel to the line L in a (X_0, Y_0) plane, respectively.

As is clear from Fig. 3, when $S = 0$, i.e., the sun is always in the X_0, Y_0 plane, and assuming that the angle of incidence n is 0 at a certain time instant, the deviation Δn thereof after the time instant coincides with a deviation $\Delta \psi$ of the yaw angle. That is, the roll angle ϕ is completely separated from the deviation Δn . However, for a practical satellite, since the sun is out of the X_0, Y_0 plane due to the orbital movement of the satellite, the variation $\Delta \phi$ of the roll angle ϕ about the X_0 axis of the satellite affects Δn unseparably, causing precise measurement of yaw angle deviation Δn to be impossible

(although there is no interference between the pitch angle θ and $\Delta\eta$).

An object of the present invention is to provide an altitude angle calculation apparatus by which the yaw
5 angle can be obtained with high precision.

According to the invention there is provided attitude angle calculation apparatus to be mounted on a satellite for calculating an attitude angle of the satellite, characterised by an earth sensor for detecting
10 deviation of an angle defined between a predetermined axis of the satellite and a straight line connecting the satellite and the geocentre of the earth; a fixed-star sensor for detecting a physical intermatrix of a fixed star; and yaw angle determination means responsive to
15 orbital position information of the satellite sent from a ground station and to outputs of the earth sensor and the fixed-star sensor to determine the yaw angle of the satellite independently of roll angle and/or pitch angle thereof.

20 Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which

Fig. 1 illustrates the above-described concept of measurement of the roll angle and the pitch angle by an
25 earth sensor;

Fig. 2 depicts the above-described concept of yaw angle measurement by a fixed-star sensor;

Fig. 3 shows a positional relation between the sun and a satellite and illustrates the above-described
30 concept of interference between yaw angle deviation and the roll angle;

Fig. 4 is a schematic block diagram of an embodiment of the present invention;

Fig. 5 depicts a mathematical model showing the

relationship between inertial space coordinates and orbital coordinates;

Fig. 6 is a schematic block diagram of another embodiment of the present invention;

5 Fig. 7 is a similar model to that shown in Fig. 5 for use in explaining the embodiment of Fig. 6;

Fig. 8 is a mathematical model showing the relationship between geocentric inertial coordinates and the position of the sun; and

10 Fig. 9 is a schematic block diagram of a further embodiment of the present invention.

Referring to Fig. 4 of the drawings, a first embodiment of an attitude angle calculation apparatus of the present invention includes an earth sensor 3, a fixed-star
15 sensor 5, and an attitude angle calculation unit 8 comprising an orbit coordinate calculation unit 4, a fixed-star vector calculation unit 6, a yaw angle calculation unit 7, and a command signal ON/OFF switch S.

The orbit coordinate calculation unit 4 calculates
20 orbital coordinates of the satellite at an arbitrary time instant using orbital information D transmitted from a ground station as a command signal. The fixed star vector calculation unit 6 receives data

from the fixed star sensor 5 and calculates therefrom a unit vector in the direction to a fixed star with respect to the coordinates of the axis of the satellite. The yaw angle calculation unit 7 receives the orbital coordinates
5 calculated by the orbit coordinate calculation unit 4, the unit vector of the fixed star under observation as calculated by the fixed-star vector calculation unit 6, and data $\phi(t)$, $\delta(t)$ from the earth sensor 3 and calculates the yaw angle $\psi(t)$ of the coordinates of the satellite
10 axis with respect to the orbital coordinates.

Fig. 5 depicts a mathematical model showing the relation of the orbital coordinates (X_0, Y_0, Z_0) to the inertial space coordinates (X_I, Y_I, Z_I) . It is assumed that the ascending node right ascension, the orbital tilting,
15 the period, and the ascending node separation angle at a time instant t_0 are given as the orbital information D from the ground command by Ω , i , J and f_0 , respectively.

In this case, the orbital coordinates are given by the following equation:

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} -\sin f \cos \Omega & -\sin f \sin \Omega & \cos f \sin i \\ -\cos i \sin \Omega \cos f & +\cos i \cos \Omega \cos f & \\ \\ -\sin i \sin \Omega & \sin f \cos \Omega & -\cos i \\ \\ -\sin f \cos \Omega & \cos f \cos \Omega & \sin \Omega \sin i \\ +\cos i \cos \Omega \cos f & -\cos i \cos \Omega \cos f & \end{bmatrix} \begin{bmatrix} x_I \\ y_I \\ z_I \end{bmatrix}$$

$$= [{}_0C_I] [x_I, y_I, z_I]^T \quad T: \text{transposition} \quad (2)$$

$$f = f_0 + 2\pi(t-t_0)/T \quad (3)$$

- 9 -

The orbital coordinate calculation unit 4 performs its operation according to equations 2 and 3 to derive the orbital coordinates.

Describing the operation of the fixed star vector calculation unit 6, the fixed star sensor 4 is mounted on the satellite with its optical axis Y_S being in coincidence with the $-Y_B$ axis of the satellite, as shown in Fig. 2. A fixed star detection level of the sensor 4 is set at a stellar magnitude of a star which is higher than third stellar magnitude, and the field of sight of the sensor 4 is selected as on the order of $4^\circ \times 4^\circ$. With these conditions, the sensor 4 mounted on a stationary satellite directed to the earth A can detect only Polaris 2. Assuming that the coordinates of the fixed star observed by the fixed star sensor 4 are (Z, X) , the unit vector $S(f)$ in the direction to Polaris 2 with respect to X_B , Y_B and Z_B of the satellite is given by the following equation:

$$S(f) = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = [{}_B C_S] \begin{bmatrix} \cos Z & \sin X \\ \cos Z & \cos X \\ \sin Z \end{bmatrix}, \quad \dots (4)$$

where $[{}_B C_S]$ is a coordinate transformation matrix determined by the relation between the fixed star sensor coordinates system and the coordinate axis of the satellite, which matrix can be obtained preliminarily.

The yaw angle calculation unit 7 receives $[0C_I]$ obtained from equation 2, the fixed star direction unit vector obtained by the equation 4, and the roll angle $\phi(t)$ and the pitch angle $\theta(t)$ measured by the earth sensor 3 and calculates the yaw angle ψ according to the following equation:

$$\sin \psi = (S_2 b_1 - a_3 b_1 - S_3 b_2 + a_2 b_3) / (a_1 b_1 - a_2 b_2), \dots (5)$$

where:

$$\begin{aligned} a_1 &= -f_1^c \cos \phi(t) \\ a_2 &= f_2^c \cos \phi(t) \\ a_3 &= f_3^c \sin \phi(t) \dots (6) \\ b_1 &= f_1^c \sin \theta(t) - f_2^c \sin \phi(t) \cos \theta(t) \\ b_2 &= f_1^c \sin \phi(t) \cos \theta(t) + f_2^c \sin \theta(t) \\ b_3 &= f_3^c \cos \phi(t) \cos \theta(t) \end{aligned}$$

$$\begin{bmatrix} f_1^c \\ f_2^c \\ f_3^c \end{bmatrix} = [0C_I] \begin{bmatrix} \cos RAS \cos DIS \\ \sin RAS \cos DIS \\ \sin DIS \end{bmatrix}, \dots (7)$$

where RAS and DIS are, respectively, the right ascension and declination by the fixed star (Polaris 2) under measurement of the fixed star sensor 4, which are obtained preliminarily.

According to this embodiment, the yaw angle can be obtained by performing operations to obtain $[f_1^c, f_2^c, f_3^c]$ by inserting the output $[0C_I]$ of the orbital coordinates calculation unit 4 into equation 7, obtaining

- 11 -

a_i and b_i ($i = 1, 2, 3$) by inserting the value of $[f_1^c, f_2^c, f_3^c]$ thus obtained and the values (ϕ, θ) obtained by the earth sensor 3 into equation 6, and calculating the desired yaw angle ψ by inserting a_i and b_i thus obtained
5 and the components (S_2, S_3) of the unit vector $S(f)$ calculated in the fixed star vector calculation portion 6 into equation (5).

According to this embodiment, the yaw angle ψ of the satellite can be obtained precisely by using the data
10 from the fixed star sensor 4, regardless of whether or not the output (ϕ, θ) of the attitude angle calculator 8 is nearly equal to zero or whether or not the orbital tilting of the satellite is nearly equal to zero.

Fig. 6 shows another embodiment of the present
15 invention in which the sun is used as the fixed star and a sun ephemeris calculator 9 is added to the attitude calculator 8. Other components are the same as or similar to those used in the embodiment shown in Fig. 4 and are thus depicted by the same reference numerals as those used
20 in Fig. 4.

With this arrangement, an orbital coordinates calculator 4 calculates the orbital coordinates of the satellite at an arbitrary time instant as described with reference to Fig. 4. A fixed star vector calculator 6, a

sun vector calculator in this case, receives data from a fixed star sensor, in this case a sun sensor 11, and calculates a unit vector in the direction toward the sun with respect to the coordinate axes of the satellite. A sun ephemeris calculator 9 operates to calculate the declination and right ascension of the sun in the direction to the sun with respect to geocentric inertial coordinates at the time instant at which the sun sensor 4 detects the sun. A yaw angle calculator 7 receives the unit vector in the direction to the sun given by the orbital coordinate calculator 4, the declination and right ascension of the sun given by the sun ephemeris calculator 9, and the data given by the earth sensor 3 to calculate the yaw angle of the satellite with respect to the orbital coordinates system.

Fig. 7 depicts a mathematical model giving the relation of the orbital coordinate system (X_0, Y_0, Z_0) to the geocentric inertial coordinate system (X_I, Y_I, Z_I) . The right ascension α at the ascending node, the orbital tilting i , the period T and the ascending node deviation angle f_0 , all at the time instant t_0 , are here assumed as being given by the orbital information contained in the ground command. The orbital coordinates at this time are given by:

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} -\sin f \cos \Omega & -\sin f \sin \Omega & \cos f \sin i \\ -\cos i \sin \Omega \cos f & +\cos i \cos \Omega \cos f & \\ \\ -\sin i \sin \Omega & \sin f \cos \Omega & -\cos i \\ \\ -\sin f \cos \Omega & \cos f \cos \Omega & \sin \Omega \sin i \\ +\cos i \cos \Omega \cos f & -\cos i \cos \Omega \sin f & \end{bmatrix} \begin{bmatrix} x_I \\ y_I \\ z_I \end{bmatrix}$$

$$= [{}^0C_I] [x_I, y_I, z_I]^T \quad \dots (8)$$

where T indicates transposition.

$$f = f_0 + 2\pi(t - t_0)/T \quad \dots (9)$$

The above operations are performed by the orbital coordinates calculator 4.

5 The operations performed by the sun vector calculator 6 will now be described with the assumption that a two-axis sun sensor of a commonly used type is available on the satellite. The two-axis sun sensor measures an azimuth angle g and an ascending vertical angle b of the sun with respect to the coordinate system of the sun sensor on the satellite, as is well known. Therefore, the unit vector $S(t)$ in the direction to the sun with respect to the satellite axis coordinates system is as given below:

$$15 \quad S(t) = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = [BCS] \begin{bmatrix} \cos g \cos b \\ \sin g \cos b \\ \sin b \end{bmatrix}, \quad \dots (10)$$

where $[BCS]$ is a coordinate transformation matrix based on the relation between the sun sensor coordinate system and the satellite axis coordinate system, which is known. The sun vector calculator 6 performs the above operation to
20 determine the unit vector $S(t)$.

The operation of the sun ephemeris calculator 9 will now be described with reference to Fig. 8, which illustrates a mathematical model showing the relation

between the sun and the geocentric inertial coordinate system. In Fig. 8, the right ascension $R(t)$ and the declination $D(A)$ of the sun are given as follows:

$$\sin D(t) = \sin \alpha \sin \varepsilon(t) \quad \dots (11)$$

$$5 \quad \cos R(A) = \cos \varepsilon(t) / \cos D(t) \quad \dots (12)$$

where $\alpha = 0.409(\text{rad})$.

$$t = 0.0172 \times D,$$

where D is the number of days counted from the equinox time of the year in which the satellite is launched to the
10 current time.

The yaw angle calculator 7 receives the unit vector obtained according to equation 10, the right ascension and declination of the sun obtained from equations 11 and 12, and the roll angle $\phi(t)$ and the pitch
15 angle $\theta(t)$ measured by the earth sensor 3 to calculate the yaw angle ψ according to the following equations:

$$\sin \psi = (S_2 b_1 - a_3 b_1 - S_3 b_2 + a_2 b_3) / (a_1 b_1 - a_2 b_2), \quad \dots (13)$$

where:

$$\begin{aligned}
 a_1 &= -f_1^c \cos \phi(t) \\
 a_2 &= f_2^c \cos \phi(t) \\
 a_3 &= f_3^c \cos \phi(t) \\
 b_1 &= f_1^c \sin H(t) - f_2^c \sin \phi(t) \cos H(t) \dots (14) \\
 b_2 &= f_1^c \sin \phi(t) \cos H + f_2^c \sin H(t) \\
 b_3 &= f_3^c \cos \phi(t) \cos H(t)
 \end{aligned}$$

$$\begin{bmatrix} f_1^c \\ f_2^c \\ f_3^c \end{bmatrix} = [0C_I] \begin{bmatrix} \cos R(t) \cos D(t) \\ \sin R(t) \cos D(t) \\ \sin D(t) \end{bmatrix} \dots (15)$$

According to this embodiment, the yaw angle ψ can be determined by inserting the output $[0C_I]$ of the orbital coordinate calculator 4 and the outputs $R(t)$ and $D(t)$ of the sun ephemeris calculator 9 into equation 15 to obtain $[f_1^c, f_2^c, f_3^c]$, inserting $[f_1^c, f_2^c, f_3^c]$ and the angles ϕ and H measured by the earth sensor 3 into the equation 14 to obtain a_i, b_i ($i = 1, 2, 3$), and inserting a_i, b_i and the component (S_2, S_3) of the unit vector $S(t)$ calculated by the Sun vector calculator 6 into equation 13.

Fig. 9 shows another embodiment of the present invention. In Fig. 9, a register 10 stores positional information β_0 of the satellite which is contained in the command signal transmitted from the ground station, and an initial correction calculator 12 receives the positional information β_0 stored in the register 10 and data from the

- 17 -

earth sensor 4 to obtain an initial value of a correction to be added to the data from the sun sensor 4. That is, the initial correction calculator 12 reads out the content β_0 of the register 10, which gives the angular relation of the position of the satellite in a plane 1 (Fig. 3) with respect to the sun at the time t_0 and the roll angle $\phi(0)$ measured by the earth sensor 3 at the same time t_0 and operates to obtain the initial correction a_0 according to the following equation:

$$a_0 = \phi(0') \sin \beta_0. \quad \dots (16)$$

A correction amount calculator 16 receives the data from the earth sensor 3, the initial correction a_0 from the initial correction calculator 12, and the angular relation between the satellite and the sun given by the orbital position calculator 4, and from them calculates the amount of correction to be added sequentially to the data from the sun sensor 4.

The orbital position calculator 4 reads a time signal Δt from a timer 14 and the content β_0 of the register 10 to calculate the angular relation $\beta(\Delta t)$ between the satellite and the sun according to the following equation:

$$\beta(\Delta t) = \beta_0 + \omega_0 \Delta t, \quad \dots (17)$$

where Δt is the time from the time instant to t_0 and ω_0 is

- 18 -

the angular velocity of the satellite in its orbit (which is $0.25^\circ/\text{min}$ when the satellite is geostationary).

Thus, the correction calculator 16 receives a_0 from the initial correction calculator 12 and $\beta(\Delta t)$ from the orbital position calculator 4 to determine a correction $\Delta\phi(\Delta t)$ according to the following equations:

$$\Delta\phi(\Delta t) = a_1 - a_0 \quad \dots (18)$$

$$a_1 = \phi(\Delta t) \sin \beta(\Delta t). \quad \dots (19)$$

The yaw angle deviation calculator 17 receives the correction amount $\Delta\phi(\Delta t)$ obtained according to equation 18, $\beta(\Delta t)$ obtained according to equation 17, and a variation $\Delta\eta(\Delta t)$ of the sun incident angle η with $\eta(t_0)$ at time t_0 being zero, which is measured by the sun sensor 4, to calculate a yaw angle deviation $\Delta\psi(\Delta t)$ according to the following equation:

$$\Delta\psi(\Delta t) = [\Delta\zeta(\Delta t) + \Delta\phi(\Delta t)] / \cos \beta(\Delta t). \quad \dots (20)$$

As mentioned hereinbefore, according to the present invention, the yaw angle of the satellite or the deviation thereof can be precisely determined regardless of the roll angle ϕ , the pitch angle H of the satellite, the orbital tilting i thereof, and/or the angular relation β between the satellite and the sun.

Designs of components in each of the aforementioned embodiments may be easily made by those skilled in the art.

- 19 -

CLAIMS

1. Attitude angle calculation apparatus to be mounted on a satellite for calculating an attitude angle of the satellite, characterised by an earth sensor (3) for detecting deviation of an angle ($\theta(t)$) defined
5 between a predetermined axis (Z_B) of the satellite and a straight line (PO) connecting the satellite and the geocentre of the earth (A); a fixed-star sensor (5) for detecting a physical intermatrix of a fixed star (2); and yaw angle determination means (4,6,7) responsive to
10 orbital position information (D) of the satellite sent from a ground station and to outputs of the earth sensor and the fixed-star sensor to determine the yaw angle ($\psi(t)$) of the satellite independently of roll angle ($\phi(t)$) and/or pitch angle ($\theta(t)$) thereof.
- 15 2. Apparatus as claimed in claim 1, characterised in that the fixed-star sensor (5) provides coordinates of the fixed star in a field of sight thereof; and in that the yaw angle determination means comprises orbital
20 coordinate calculating means (4) responsive to the orbital position information to calculate orbital coordinates of the satellite, fixed-star vector calculating means (6) responsive to an output of the fixed-star sensor for calculating a unit vector in a direction to the
25 fixed star with respect to coordinates of the satellite axis, and yaw angle calculating means (7) responsive to the outputs of the earth sensor, the orbital coordinate calculating means and the fixed-star vector calculating means to calculate the yaw angle of the
30 coordinates of the satellite axis with respect to the orbital coordinates.

3. Apparatus as claimed in claim-1, characterised in that the fixed star is the sun; and in that the yaw angle determination means comprises orbital coordinate calculating means (4) responsive to an output of the
5 earth sensor (3) for calculating orbital coordinates of the satellite, a sun sensor (11) for determining azimuth angle and angle of incidence of the sun with respect to coordinates of the sun sensor, sun vector determining means (6) responsive to an output of the sun
10 sensor for calculating a unit vector in a direction to the sun with respect to coordinates of the satellite axis, sun ephemeris calculating means (9) for calculating the right ascension and the declination of the sun with respect to geocentric inertial coordinates, and a yaw
15 angle calculator (7) responsive to outputs of the earth sensor, the orbital coordinate calculating means, the sun vector calculating means, and the sun ephemeris calculating means for calculating the yaw angle of the satellite axis coordinates with respect to the orbital
20 coordinates.

4. Apparatus as claimed in claim 1, characterised in that the fixed star is the sun; and in that the yaw angle determination means comprises a register (10) for storing positional information of the satellite and
25 its orbit received from the ground station as a command signal, initial correction calculating means (12) responsive to the position information stored in the

register and an output of the earth sensor at a time instant at which the command signal is transmitted for calculating an initial value of correction, a timer (14), orbital position calculating means (4) responsive to the
5 satellite position stored in the register and an output of the timer for calculating an angular relation between the satellite and the sun, a sun sensor (5) for measuring a relative variation of an incident angle of the sun, correction amount calculating means (16) responsive to
10 outputs of the earth sensor, the orbital position calculating means and the initial correction calculating means for calculating a correction amount sequentially, and yaw angle deviation calculating means (17) responsive to an output of the sun sensor and the correction amount
15 calculating means for calculating deviation of yaw attitude angle of the coordinates of the satellite axis with respect to the orbital coordinates.

FIG. 1

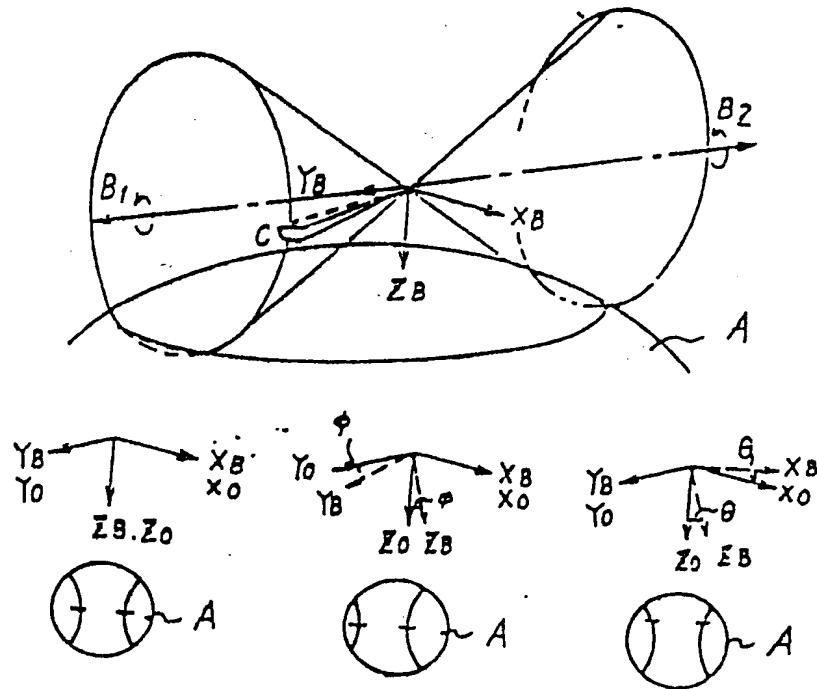


FIG. 2

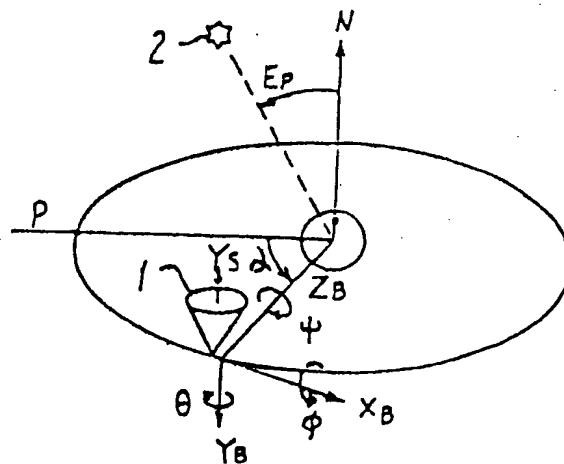


FIG. 3

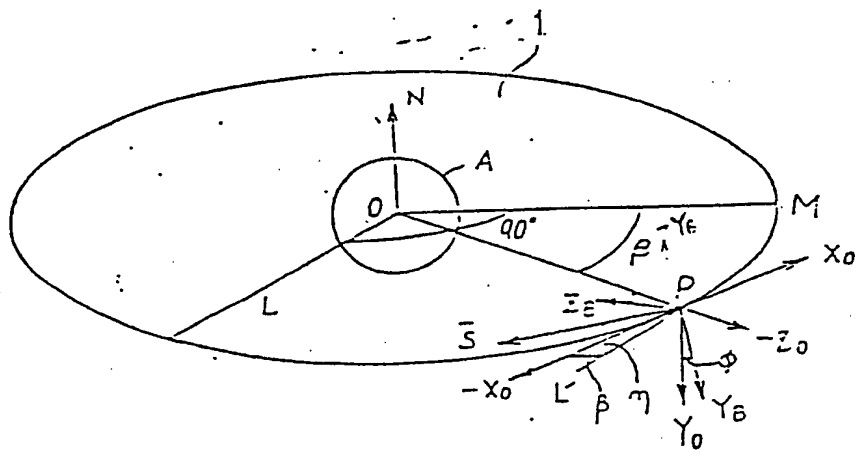


FIG. 4

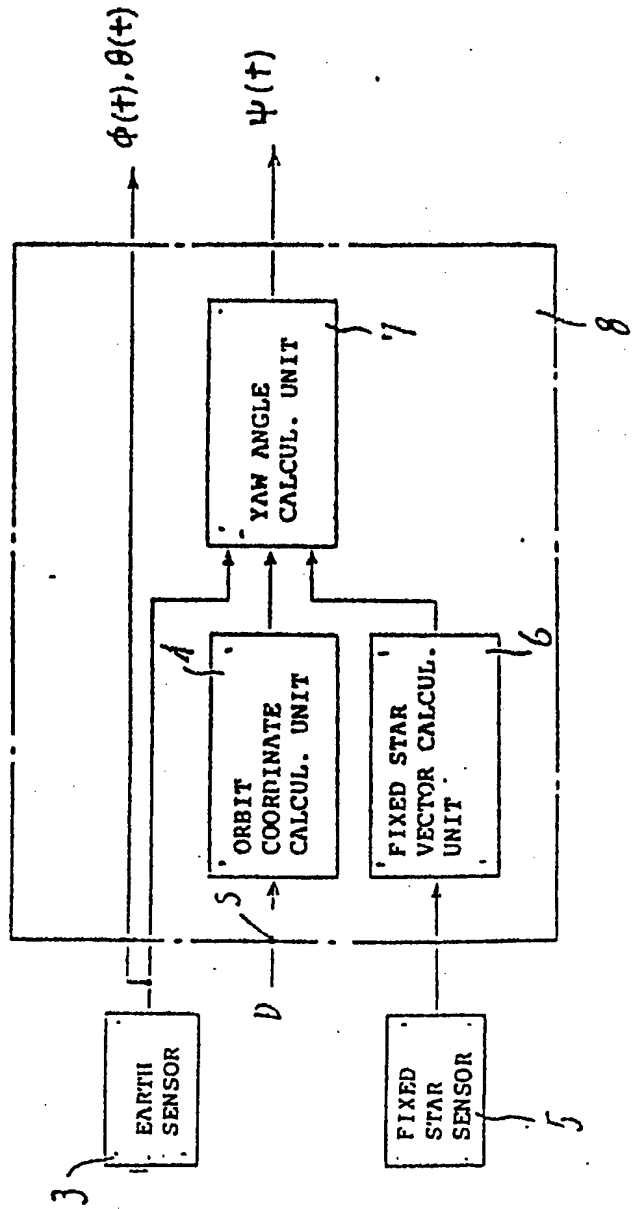


FIG. 5

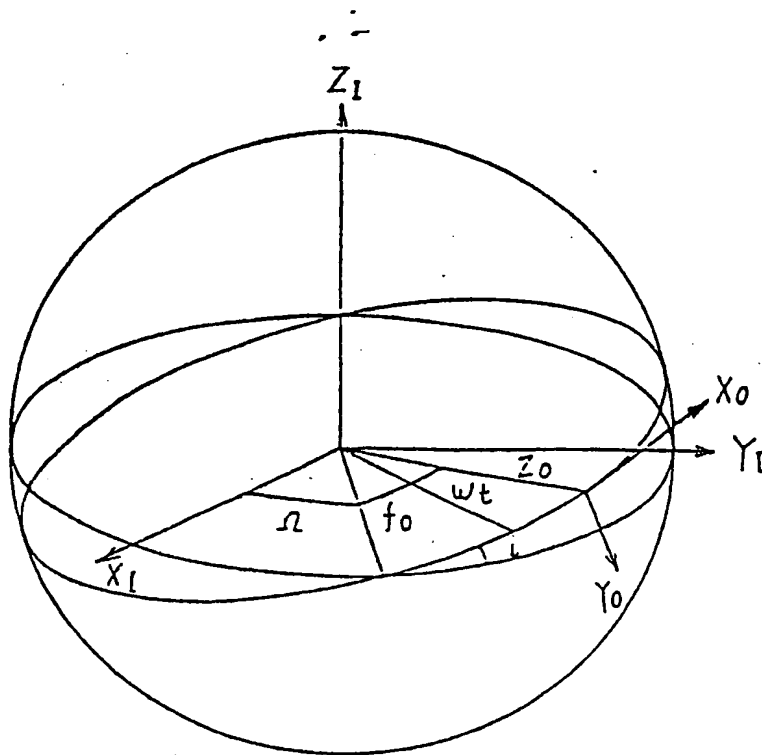


FIG. 6

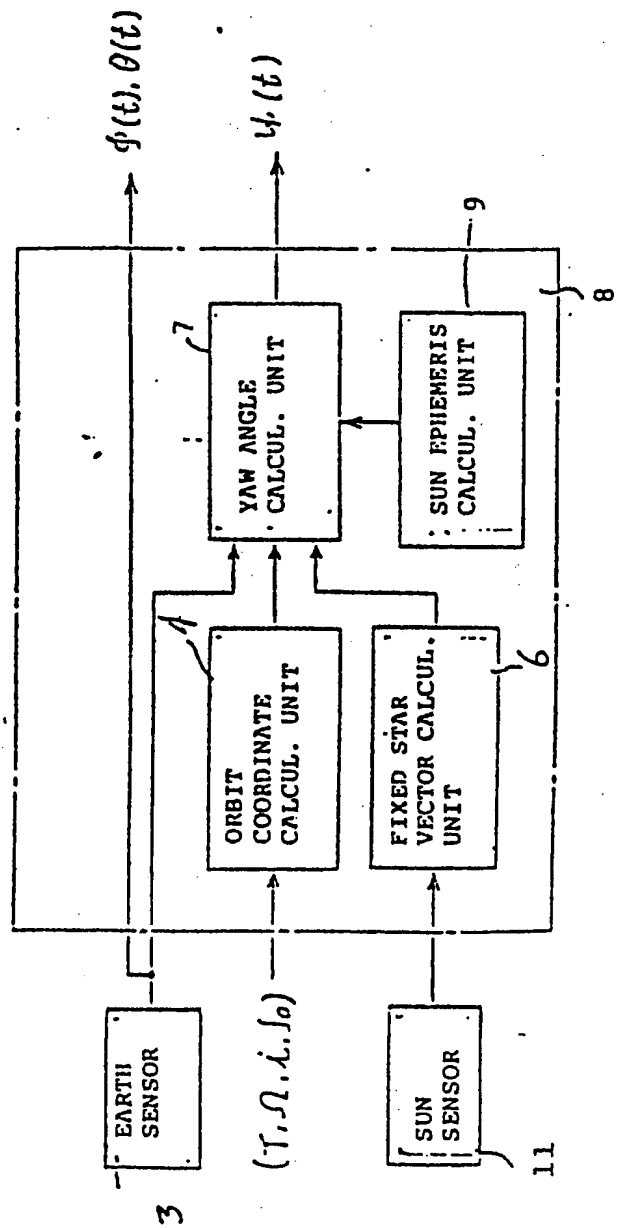


FIG. 7

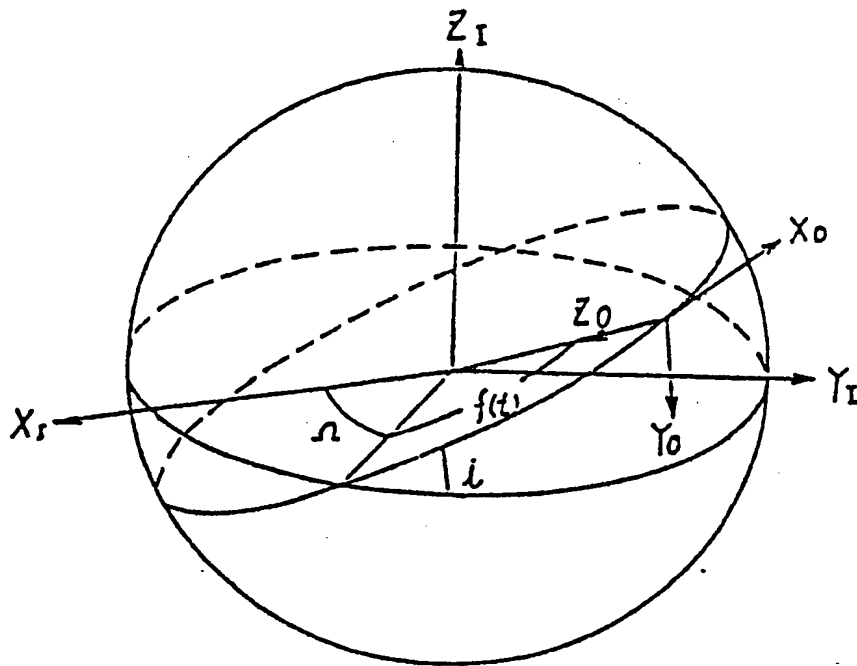


FIG. 8

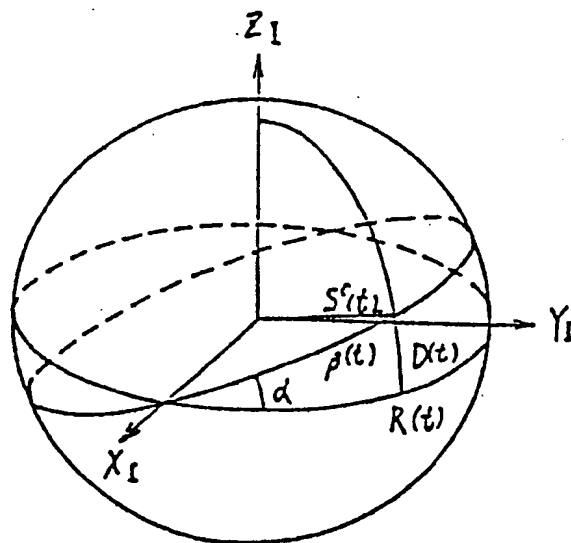


FIG. 9

